Kinematics of π^0s contributing to NC Background

August 20, 2014

Tagged π^0s from K$^+$ Beam

- Recall David Jaffe's idea of using tagged π^0s from K$^+$ beam to study NC background

Utility of low momentum (<1GeV/c) K+ beam

1. Directly address detection efficiency of K+ from proton decay in Liquid Argon TPC (LAr), Liquid Scintillator (LS) or Water-based Liquid Scintillator (WbLS) detectors

2. The "electronic bubble chamber" nature of a LAr detector offers the following potential capabilities

   −Stopped $K^+ \to \pi^+\pi^0$ (BR=21%) gives a monoenergetic 205 MeV/c pi0 beam

   − $K^+ \to \pi^+\pi^0$ decay-in-flight can provide tagged pi0 beams in a wider momentum range

- What are the kinematics of π^0s contributing to NC background?
- How many π^0s would be needed to effectively study this background?
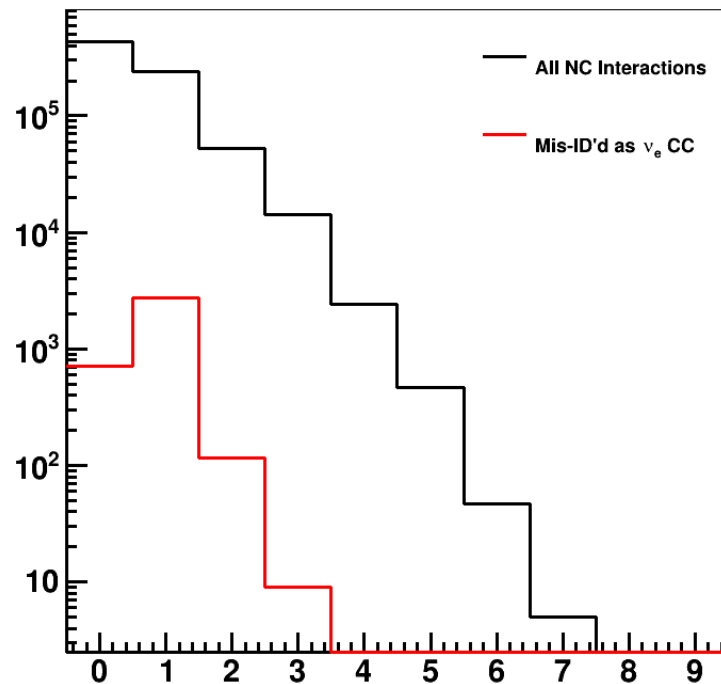
From Fast MC

ν_e reconstructed energy spectra by (true) interaction type:

Quasi-elastic   Resonance Production
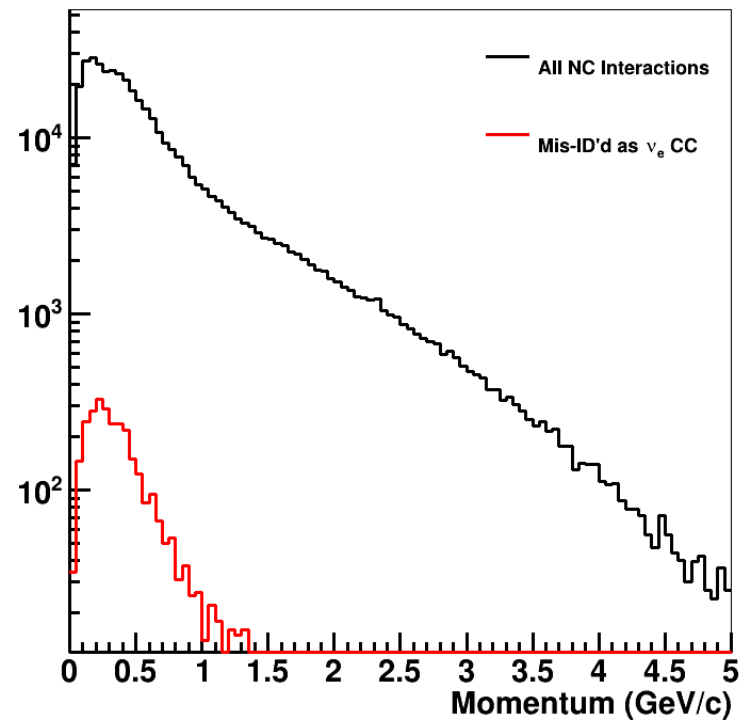
DIS (W<2.7)   DIS (W>2.7)
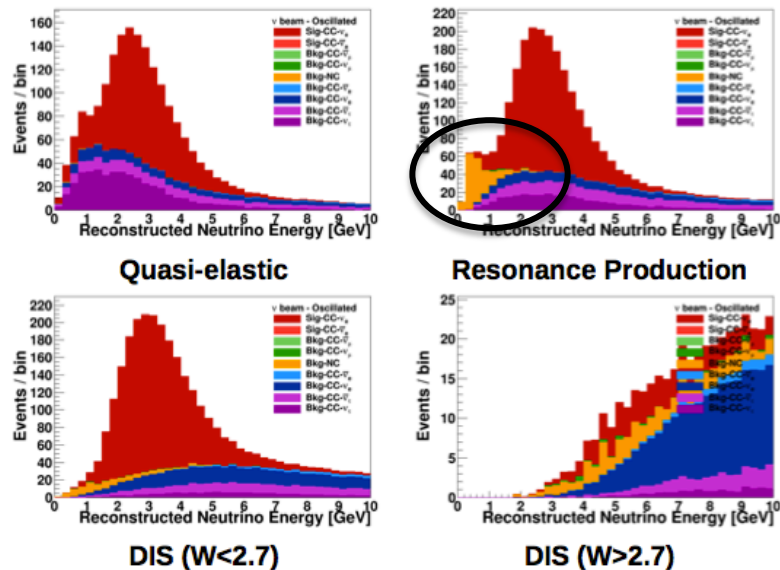
- Fast MC ν_e selection criteria
  - Energy threshold to reconstruct
  - Conversion distance < 2 cm
  - Does not make π^0 mass with any other EM particle
  - e/γ separation using dE/dx: applied probabilistically as a function of shower energy
  - Efficiency applied probabilistically as function of shower energy and Bjorken Y
  - Tau rejection based on p_T effective against NC; needs tuning, not yet included in following studies
- Resonance production with low reconstructed energy is most troublesome source of NC background
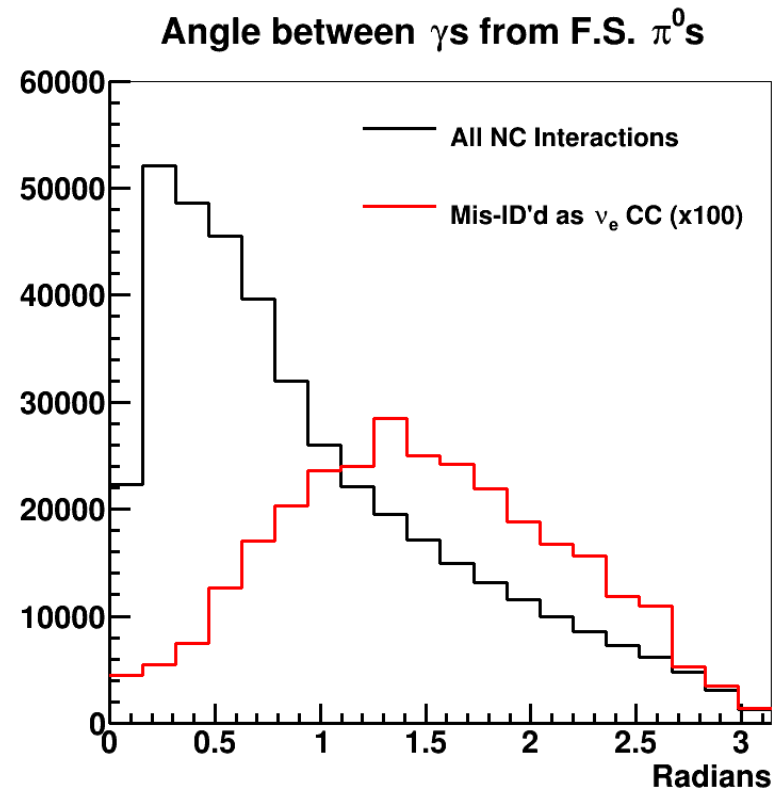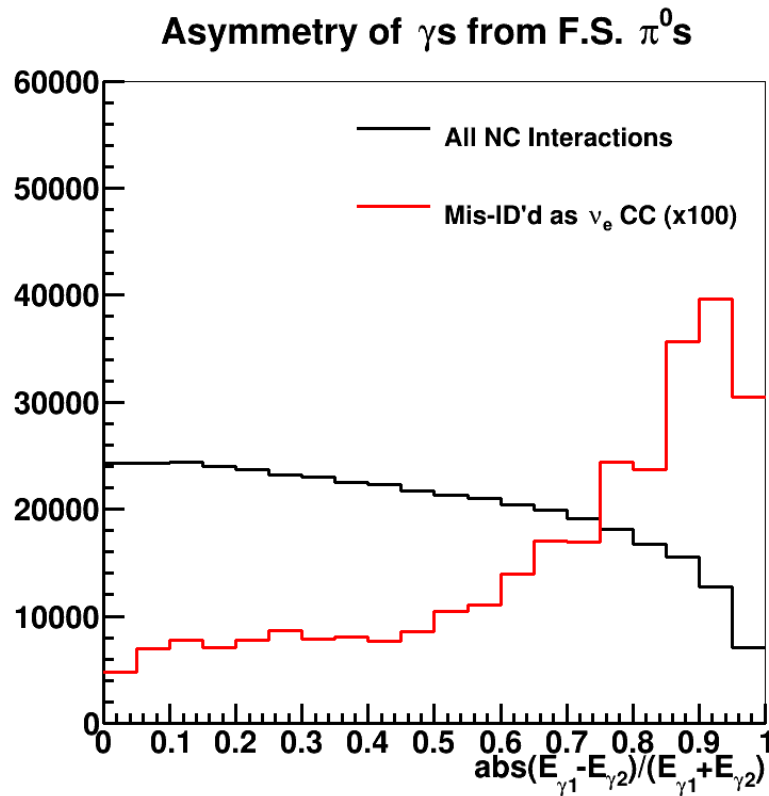
Final State π^0s

Number of π^0s in Final State

— All NC Interactions

— Mis-ID'd as ν_e CC

Momentum of π^0s in Final State

— All NC Interactions

— Mis-ID'd as ν_e CC

Momentum (GeV/c)

Low-momentum, single-pion final states contribute most to background.
Pions with momentum < 1 GeV are need to study this background.

γs from Final State π⁰s

Asymmetry of γs from F.S. π⁰s

Angle between γs from F.S. π⁰s

(left plot) legend:
— All NC Interactions
— Mis-ID'd as ν_e CC (x100)

x-axis: $abs(E_{\gamma 1}-E_{\gamma 2})/(E_{\gamma 1}+E_{\gamma 2})$

(right plot) legend:
— All NC Interactions
— Mis-ID'd as ν_e CC (x100)

x-axis: Radians

- Note: BG events scaled x100 for comparison
- Asymmetry plot matches expectation – expect easier to miss a gamma when energies are asymmetric.
- Angular distribution is a result of low-energy gammas contributing most: see 2D plots later.
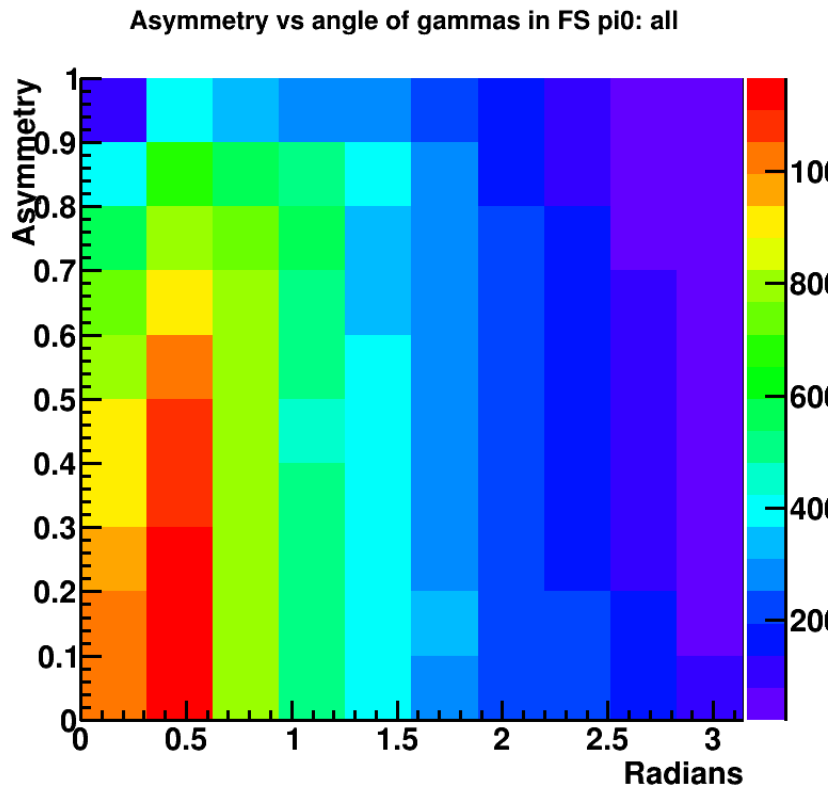
γs from Final State π^0s
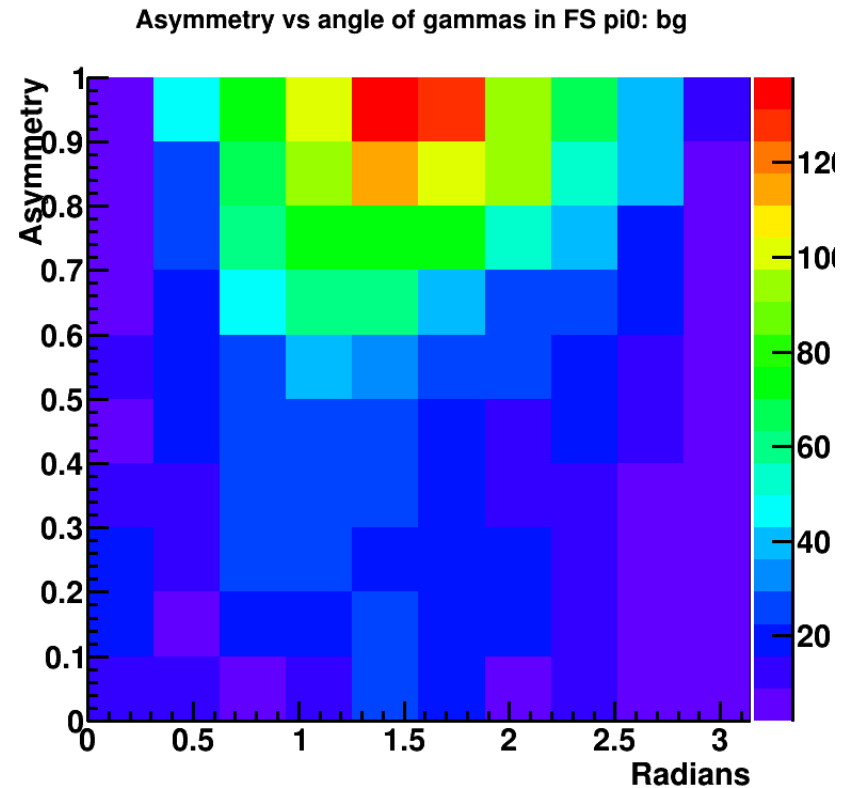
Minimum γ energy from F.S. π^0
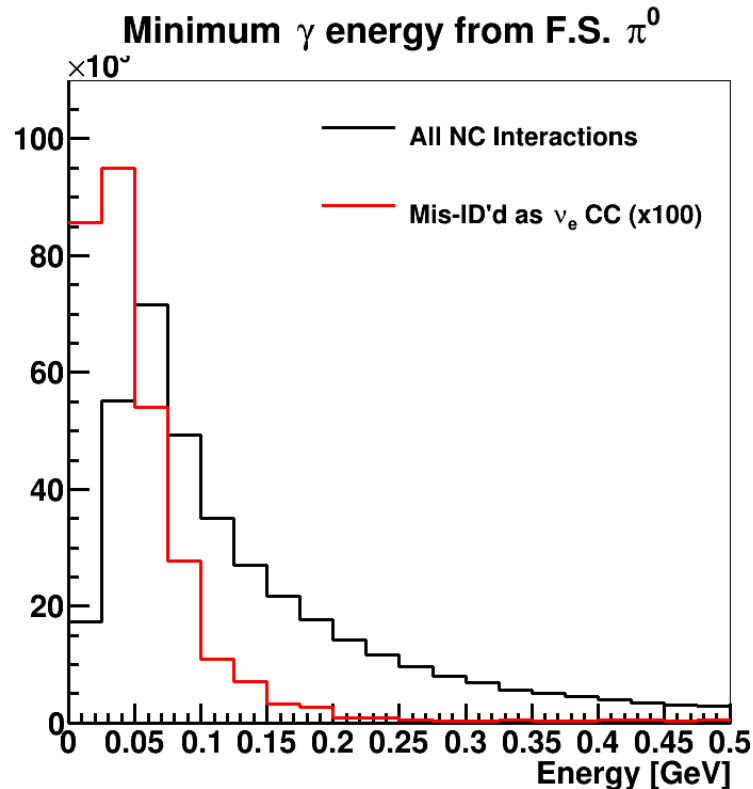
- e/γ separation using dE/dx: applied probabilistically as a function of shower energy
- Based on results from uBooNE simulation
- Linearly interpolate acceptance probability between:
  - 100% at 0
  - 50% at 250 MeV
  - 8% at 1.5 GeV
- Acceptance flat at 8% for E>1.5 GeV
- Since e/γ separation is least effective at lower shower energies and there is some probability for showers to go below detection threshold, residual background dominated by low energy gammas
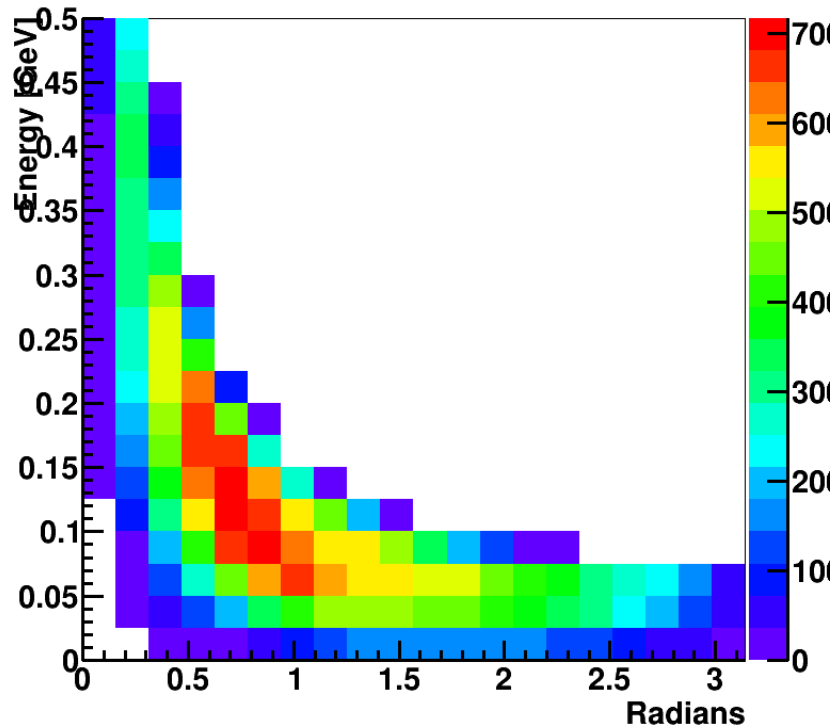
Asymmetry vs Angle

All:

Asymmetry vs angle of gammas in FS pi0: all

Background:

Asymmetry vs angle of gammas in FS pi0: bg

Minimum Energy vs. Angle

All:

Background:
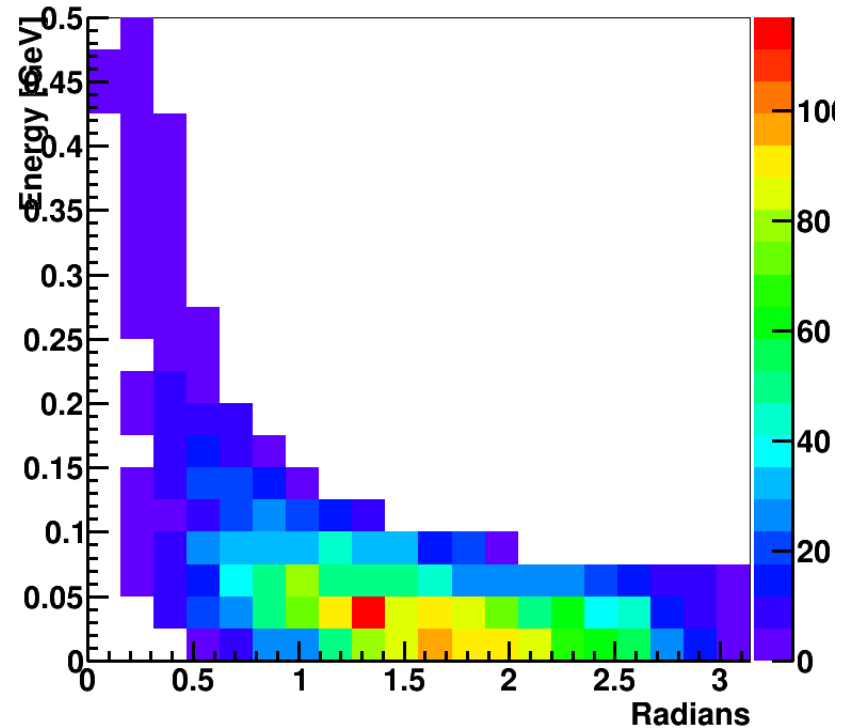

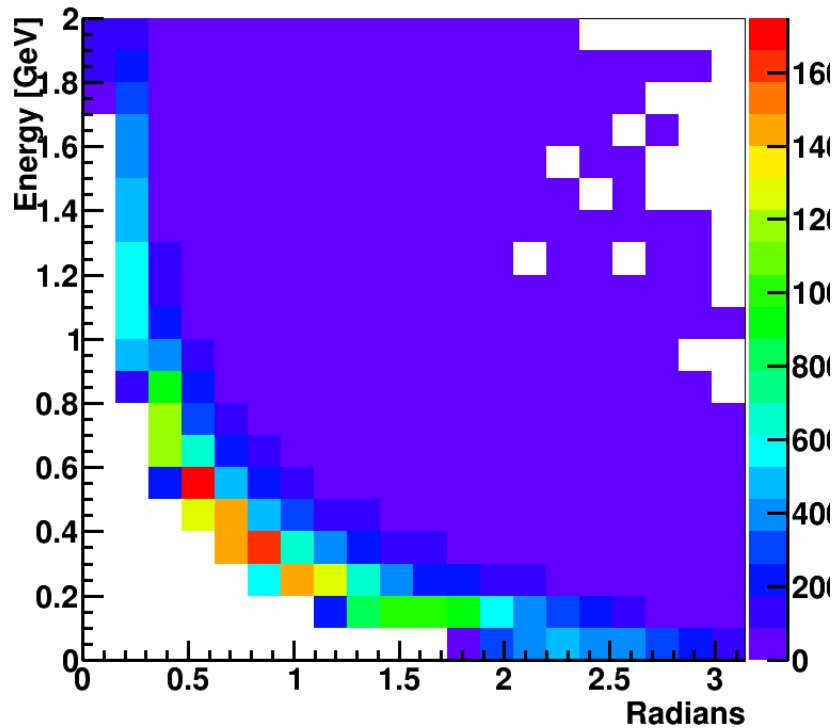Minimum energy vs angle of gammas in FS pi0: all

Minimum energy vs angle of gammas in FS pi0: bg
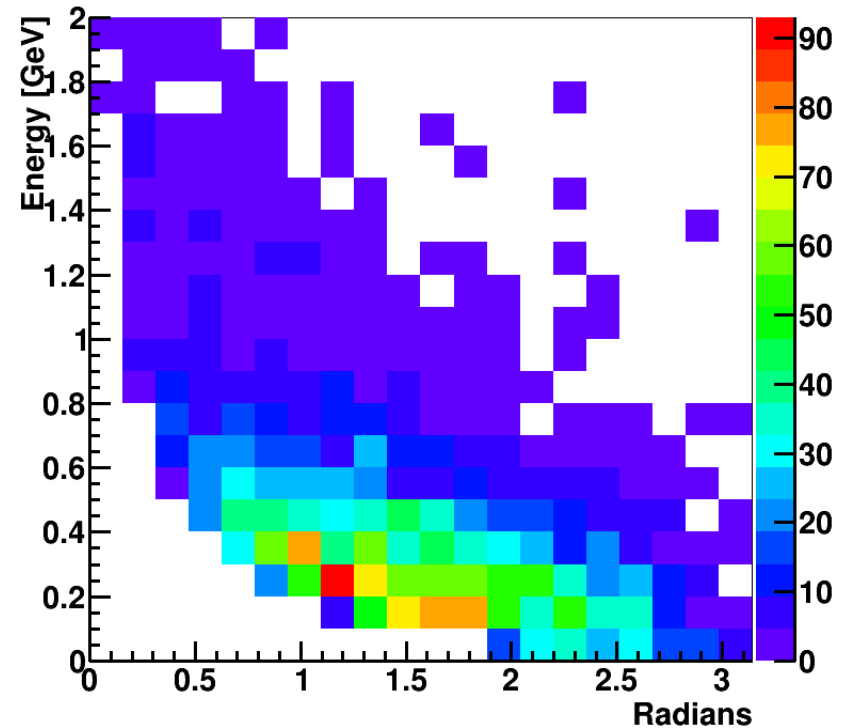
Pion momentum vs Angle

All:

Pi0 momentum vs angle of gammas in FS pi0: all

Background:

Pi0 momentum vs angle of gammas in FS pi0: bg

How many π^0s needed?

- Subject of some discussion:
  - Plots shown here made with ~400k π^0s with most < 1 GeV, but <1% of these contribute to residual background (~3000 events). Would want higher statistics than shown in this study to really study residual background: ~1M π^0s
  - Start from expected number of NC events (~2500/year for 35kt, 80-GeV beam), assume 20 years of running, and 10x the expected event rate to study the background: 500k π^0s
  - To validate 5% background normalization uncertainty: 400 events contributing to residual background needed, x100 to allow selection of residual background at level shown in this study, x10 for multiple momentum bins: 400k π^0s

What can beam provide?

- Existing FNAL test beam: ~1 π^0 per day

- 800 MeV/c K^+ beam from David's talk:
  - Assume 666 Hz beam (1.5 ms between particles) to avoid pileup/space charge issues (??)
  - 40k K^+/1×10^{12} POT (π/K = 7) of which ~1300 decay within 1 m: useful rate in 666 Hz beam = 2.7 Hz
  - Using FNAL test beam duty factor: 1M π^0 would take ~60 days

Questions to answer

- How much gain in sensitivity if NC background eliminated completely?
  - Easy to test in GLoBES but lots of caveats
  - Are systematic uncertainties going to dominate at low-energy such that increasing signal to BG in this region doesn't help?
  - Are systematic uncertainties less important at low-energy because measurement at 2nd oscillation max is largely shape based and measuring larger asymmetry?
- Possible to eliminate NC background if this sample could be collected?
- What are real pile-up/space charge issues in test beam?